DRP-1-16
May 1994

Dredging Research
Technical Notes

The PLUme MEasurement System (PLUMES): A Commercially Available System

Purpose

This technical note describes a commercially available field data collection system that can measure suspended sediment concentrations and currents at dredging operations sites. It has the capabilities of the PLUme MEasurement System (PLUMES), described in *Dredging Research Technical Notes* DRP-1-06 (Kraus and Thevenot 1992).

Background

During dredging and dredged material disposal operations, clouds or plumes of suspended sediment are produced at the sites of these operations. The temporal and spatial distribution of turbidity from these plumes, and the fate of the suspended sediment in them, are important environmental concerns. PLUMES was developed to obtain measurements that provide quantitative information on these factors.

During the period 27 September to 4 October 1991, PLUMES was successfully used to monitor the plume around a dredging operation at Tylers Beach, Virginia (Thevenot, Prickett, and Kraus 1992). For that project, the primary acoustic system was a four-beam 2.4-MHz Broad-Band Acoustic Doppler Current Profiler (BBADCP), manufactured by RD Instruments (RDI) of San Diego, California, and a separate single-beam 600-kHz transducer. Subsequently, working with RDI, a five-beam 600-kHz PLUMES was developed under the Dredging Research Program (DRP).

A commercial system now available from RDI has PLUMES capabilities. The purpose of this technical note is to provide information on the characteristics and capabilities of this system. This technical note also discusses the theoretical relationship between acoustic backscatter intensity and suspended sediment concentrations.

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Additional Information

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Note: The contents of this technical note are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such products.

System Description

The system is a BBADCP (Spain and Gordon 1992) with additional capabilities. It has five transducers on a single head (Figure 1). Data from the four transducers on the outside are used to calculate horizontal and vertical current velocities. The center transducer points straight down and measures acoustic backscatter intensity. Data from these measurements are used to calculate suspended sediment concentrations. The system can be mounted on the side of a survey boat or towed at depth in a towed body.

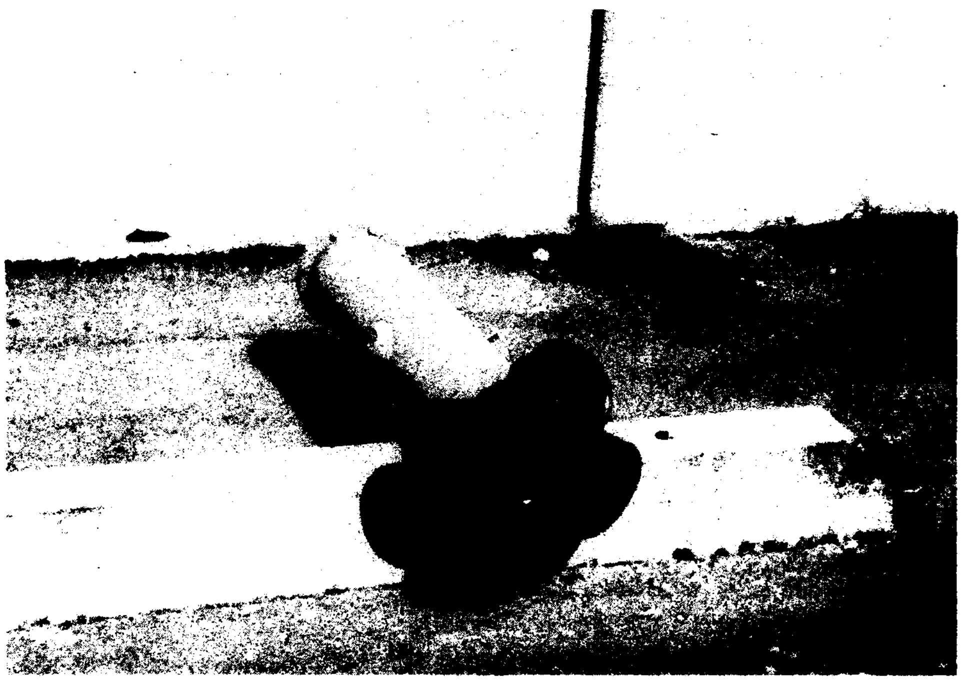

Figure 1. System head with its five transducers

Current Measurements

The BBADCP produces current velocity measurements in a series of "bins" along each beam out to 40 to 65 m. The maximum operational range depends on the acoustic energy loss mechanisms. The minimum recommended size of each bin, which determines the maximum vertical resolution of the current measurements, is 25 cm. Smaller bin sizes will significantly degrade the accuracy of the measurements. As a result of the 30-deg (0.5 rad) orientation of each beam from the vertical, the beams diverge away from the instrument. At maximum range, the beams span approximately 55 m horizontally. The BBADCP calculates the horizontal and vertical current velocities from these four beams, assuming that the currents are uniform over the entire region covered by the beams.

Taking into account the orientation of the four velocity beams, the BBADCP measures the currents 35 to 55 m below the instrument when operating at maximum range. The BBADCP can detect the bottom at a distance closer than approximately 55 to 90 m and can measure the velocity of the instrument over the bottom.

Acoustic Measurements

The fifth beam of the system is used to measure acoustic backscatter intensities. At 600 kHz, the acoustic wavelength is much greater than the size of the suspended sediment particles at most dredging operations sites. As the wave passes through the water, it causes the particles to move back and forth; however, their motion lags behind the wave. This lagging oscillation reradiates acoustic energy in all directions, with some going back toward the source. The acoustic energy detected by the source transducer is called backscatter, and its intensity depends on the number of sediment particles in the beam. Thus, the intensity of the backscatter provides information on sediment concentration. This phenomenon is known as "Rayleigh scattering." The backscatter intensity also depends on the size of the particles and the source frequency; the intensity decreases with decreasing particle size and decreasing frequency.

Four loss mechanisms decrease the amount of backscattered acoustic energy received by the system. The first loss mechanism is geometric spreading. The acoustic wave front expands along its path, and the acoustic energy per unit area decreases with distance along the wave path. Spreading loss is independent of frequency.

The second loss mechanism, absorption of energy by the water, increases with increasing frequency. The third loss mechanism is viscous attenuation. The lagging oscillations of the sediment particles in the beam cause shear forces that result in an energy loss due to the viscosity of the water. This viscous effect depends on the shape of the particles and increases with increasing frequency and increasing concentration. The

fourth loss mechanism is scattering, caused by spreading of acoustic energy in directions that do not contribute to the acoustic energy returning to the instrument.

The net result of the frequency dependence of backscatter intensity and the frequency-dependent loss mechanisms is that, as the frequency increases, smaller sediment concentrations and smaller grain sizes can be measured, but the range over which the measurements can be made decreases. The operating frequency of the system (i.e., 600 kHz) will measure a range of grain sizes and concentrations that is adequate for most dredging operations sites.

There may be an upper limit of suspended sediment concentration that can be measured acoustically. This limit is a result of a mechanism known as multiple scattering. The acoustic energy scattered in the directions that, for typical concentrations, do not contribute to backscatter may for high concentrations be rescattered by other particles and produce secondary backscatter contributions. When this secondary backscatter becomes significant, the relationship between concentration and backscatter intensity cannot be determined. Some recent work by Hay (1991) suggests that the limiting concentration is not likely to be reached in a residual dredged material plume.

The acoustic backscatter intensity measurements are made vertically. Thus, the intensity is measured to depths of 40 to 65 m beneath the instrument (i.e., the maximum along-beam range). The resolution of the fifth beam is independent of the resolution of the current-measuring beams. It may be desirable under certain conditions to make the sediment concentration measurements at the maximum resolution of the system, that is, in 10-cm bins. Because the system is limited to 128 range bins, changing the resolution can change the range.

Deployment and Ancillary Instruments

For shallow-water deployments, the BBADCP system is mounted in a bracket (Figure 2). The system is easily suspended from the gunwale of a small survey boat and is held in place by clamps that screw against the inside of the gunwale. Pins in the mount are taken out to lower and raise the BBADCP. In this configuration, the data are transmitted over a seven-conductor neoprene-jacketed electronics cable, which is subject to negligible strain.

For deep-water deployments, a towed body is used (Figure 3). In this configuration, the data are transmitted over a seven-conductor electromechanical tow cable that has haired fairing on it for approximately 20 percent of its length. To tow the system at a depth of 300 m, the tow cable must be approximately 1,000 m long. The towed body is manufactured by Endeco/YSI, Marion, Massachusetts. It is constructed of fiberglass in a dihedral-winged, passive depressor design. Mounting the

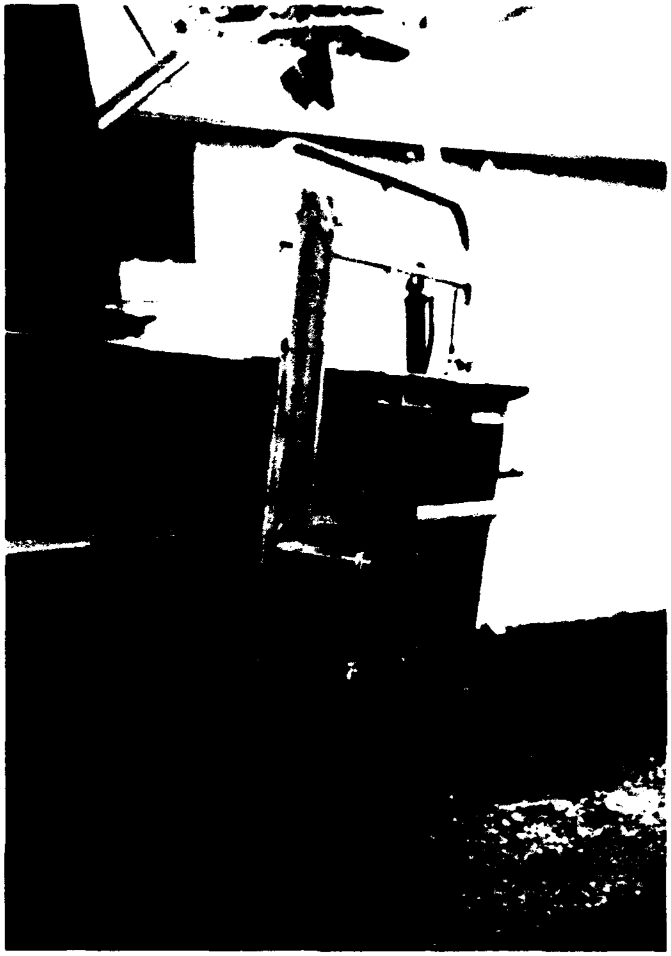

Figure 2. Over-the-side mounting for shallow-water operations

BBADCP system in the towed body requires that a 90-deg (1.6 rad) adapter be installed on the BBADCP transducer. This is a relatively simple and quick operation for the user.

The BBADCP system mounts in the towed vehicle with the lower edges of the transducer faces nearly flush with the bottom of the towed body. Approximately one fourth of the BBADCP's cylindrical pressure housing is mounted in the interior of the towed body, while the remainder protrudes from the rear of the towed body and is covered on the end with a fiberglass fitting. The cover (Figure 3) looks like the nose of a torpedo and serves a dual purpose. First, it covers the BBADCP connector, the end of the sea cable, and the cable to the external sensors, to limit their motion during towing. Second, the cover improves the hydrodynamics of the towed body, reducing flow-induced acoustic noise and improving stability.

Figure 3. Towed-body mounting for deep-water operations

The manufacturer claims that the vehicle can accommodate tow speeds from 2 to 12 knots (1 to 6 m/sec) with stable roll and pitch characteristics. The manufacturer specifies the maximum roll to be ±2 deg (0.03 rad) and the maximum pitch to be ±3 deg (0.05 rad) at 10 knots (5 m/sec). DRP researchers have successfully towed the system operationally at tow speeds up to 4 knots (2 m/sec).

Sensors mounted inside the BBADCP system measure the pitch and roll of the instrument as well as its compass heading. These sensors are attached to the transducer head so that they are operational in both the right-angle and in-line configurations. A conductivity-temperature-depth gauge (CTD) and an optical backscatter sensor (OBS) are also mounted in the towed body. The OBS, CTD, and BBADCP data are telemetered to shipboard via the tow cable.

When the BBADCP system is attached to the side of a survey boat, the normal practice is to use the CTD with the optical backscatter sensor attached as a separate profiling device. To perform this operation, the survey boat is stopped and the sensors are lowered to the bottom near the BBADCP system and then immediately raised and placed on the vessel. This produces a continuous CTD and optical backscatter profile. The CTD data provide information on the density structure at the site. The OBS responds to sediment in the water but not to biological backscatterers. Thus, the OBS data can be used to identify biological sources of acoustic backscatter.

Software

The software is of two types: data acquisition software (DAS) and postprocessing software. DAS displays and stores all acoustical, navigation, and ancillary data acquired during the survey. The DAS was developed under DRP for PLUMES and has been modified to operate the RDI system. The postprocessing software will assist Corps field offices in data reduction and analysis. (Postprocessing software being developed under the DRP is scheduled for completion in 1994.)

DAS displays the data both graphically and numerically on a VGA monitor (Figure 4), while storing it on the computer's hard disk drive. The data displayed on the monitor are explained in Table 1. Below the numerical data there are three running displays (Figure 4): one shows the acoustic backscatter intensity for the fifth beam while the other two show east-west and north-south current velocities. The depth resolutions and ranges of these displays are operator controllable.

The current data stored on disk are raw data unaffected by display settings. The operator can also control the color-coding of the displays. The backscatter intensity data are corrected for losses due to geometric spreading and seawater absorption prior to display. The backscatter intensity

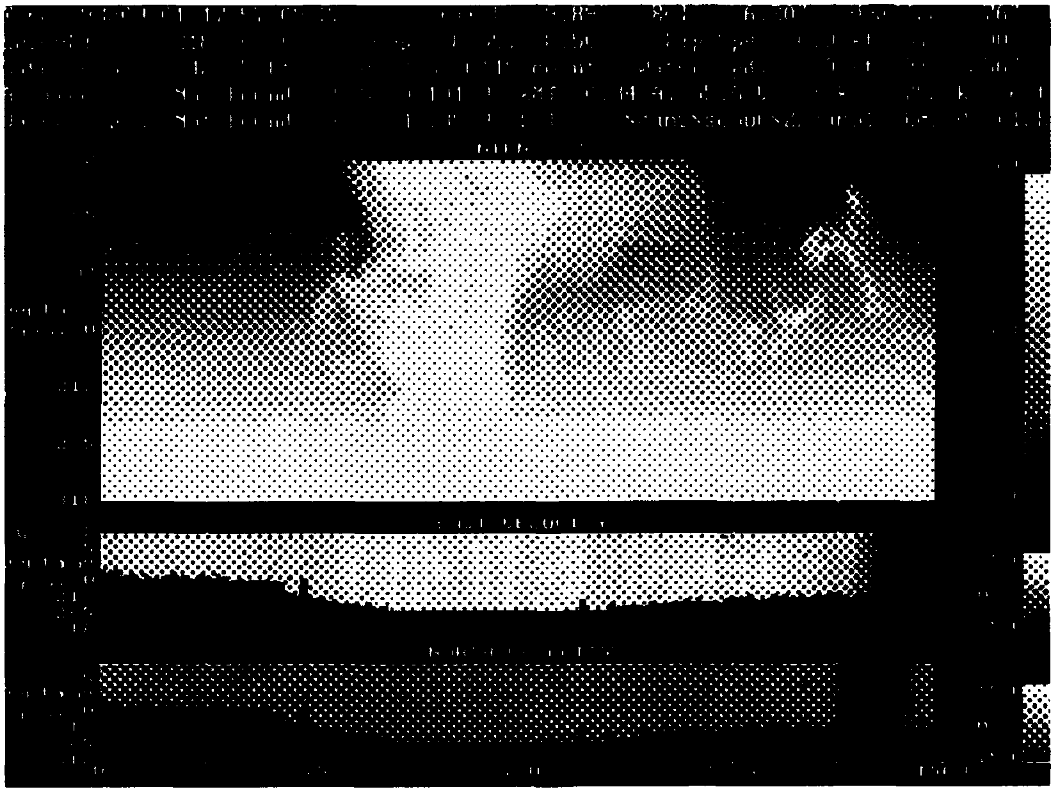

Figure 4. Data acquisition software display screen

Table 1
Parameters Numerically Displayed on Monitor by DAS During a Survey

Displayed Description	Units	Meaning
Time	yr/mo/day, hr, min, sec	The current date and time referenced to the host computer clock.
Pitch	degrees	Forward/backward tilt of BBADCP, positive when forward-looking beam (beam 3) is up.
Roll	degrees	Sideward tilt of BBADCP, positive when starboard beam (beam 2) is down.
Heading	degrees	Compass direction of forward-looking beam, less offset entered by operator (firmware command). In towed configuration, this is the direction of motion of the towed body. In the boat-mounted configuration, this is the direction of motion of the boat.
Ensemble	count	The number of the profile measurement; the first profile in the record is 1.
ADCP, CTD[1] Temp	degrees Celsius	Temperature measured by temperature sensor mounted in BBADCP transducer head and by the CTD.
Ship Spd	knots	The speed of the ship over the bottom. Works only when bottom tracking.
Dir	degrees	True direction of ship's travel over bottom, from BBADCP compass and operator-entered variance. Works only when bottom tracking.
Submergence[1]	feet	Depth of towed body. Fixed at 3.28 ft for the shallow-water configuration.
Raw Ctdy[1]	counts	The CTD conductivity in counts before conversion to engineering units.
Water Spd	knots	Average current speed for bins 2, 3, and 4, over bottom when bottom tracking or less speed entered by operator when not bottom tracking.
Dir	degrees	Average current direction for bins 2, 3, and 4, magnetic, less offset entered by operator.
Altitude	feet	Distance from BBADCP to bottom, only when bottom tracking.
OBS[1]	volts	Output voltage of the optical backscatter sensor.

(Continued)

[1] Deep-water configuration only.

Table 1 (Concluded)		
Displayed Description	**Units**	**Meaning**
XMT	amps, volts	Current and voltage to the fifth beam transducer when transmitting a ping.
Disk	kilobytes	Amount of data storage capacity left on the drive specified in item 1 of the DAS menu.
Water Depth	feet	Water depth, sum of "Submergence" and "Altitude." Works only when bottom tracking.
VDC	volts	Voltage at the input to the BBADCP.
File	NA	Name of the file in which data are being stored.

data stored on disk are uncorrected. DAS also stores position data from navigation devices operating during the survey.

RDI provides software ("BBLIST") that reads the DAS data files and produces ASCII data files for analysis.

Suspended Sediment Samples

Backscatter intensity and viscous loss depend on grain size and sediment type. Therefore, in most situations it is necessary to take suspended sediment samples during the survey to use in analyzing the acoustic intensity measurements. These samples can be taken either by water sample bottles or by continuously pumping out samples through a tube in the water. Water sample bottles are lowered to the desired sample depth while open. An electronic signal or a mechanical "messenger" sent down the cable closes a bottle, capturing the sample at that depth. When pumping out a sample, the intake end of the tube is placed at the desired sample depth. Sediment samples are analyzed in the laboratory for sediment concentration and grain-size distribution.

The sonar equation (Clay and Medwin 1977) relates the received backscattered intensity to the source strength, the scattering strength of acoustic scatters in the beam, and the effect of loss mechanisms. As previously discussed, the scattering strength of suspended particles is related to the concentration. Given a particular grain size, measured acoustic intensity, and BBADCP performance parameters, the sonar equation calculates the maximum possible concentration of suspended sediment of that size that could produce the measured backscattered acoustic intensity.

A direct application of the sonar equation would require that the calculation be performed for every grain size present in the plume, weighting the

results according to the percent occurrences of the grain sizes to account for their actual contributions to the measured intensity. In practice, assumptions about the statistical properties of the grain-size distribution can simplify the calculations.

Summary

PLUMES research under the DRP has resulted in commercially available systems for determining suspended sediment concentrations and transport at the sites of dredging operations. Software for acquiring and displaying the data in the field is available from the DRP. As part of the DRP, work is currently under way to develop postprocessing software for Corps field office use.

References

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